

The physics mechanisms of light and heavy flavor v_2 and mass ordering in AMPT

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Abstract. A Multi-Phase Transport (AMPT) model has been shown to describe experimental data well, such as the bulk properties of particle spectra and elliptic anisotropy (v_2) in heavy ion collisions. Recent studies have shown that AMPT describes the v_2 data in small system collisions as well. In these proceedings, we first investigate the origin of the mass ordering of identified hadrons v_2 in heavy ion as well as small system collisions. We then study the production mechanism of the charm v_2 in light of the escape mechanism for the light quark v_2 .

1. Introduction

Relativistic heavy ion collisions aim to create the quark-gluon plasma (QGP) and study its properties at the extreme conditions of high temperature and energy density [1, 2]. The collective flow as a soft probe is often used to study the QGP properties in experimental and theoretical investigations. Both hydrodynamics [3, 4] and transport theory [5] can describe the bulk data in heavy ion collisions. For example, the string melting version of A Multi-Phase Transport (AMPT) model [5, 6] reasonably reproduces particle yields, p_\perp spectra, and v_2 of low- p_\perp pions and kaons in central and mid-central Au+Au collisions at 200A GeV and Pb+Pb collisions at 2760A GeV [7]. The small system data can be also satisfactorily described by AMPT [8].

Recent studies have shown that light parton v_2 is mainly generated by the anisotropic parton escape from the collision zone and hydrodynamics may play only a minor role [9, 10]. It suggests that the mass ordering of v_2 , commonly believed as a signature of hydrodynamics, may arise from other mechanisms. In these proceedings, we first investigate the physics mechanisms of mass ordering in AMPT [11, 12]. We then study the production mechanism of the charm v_2 in light of the escape mechanism for the light quark v_2 .

2. Model details and analysis method

We employ the string melting version of AMPT [5, 6] in our study. The model consists of four components: fluctuating initial conditions, parton elastic scatterings, quark coalescence for hadronization, and hadronic interactions. The partons interaction are modeled by Zhang's parton cascade (ZPC) [13]. We use Debye screened differential cross-section $d\sigma/dt \propto \alpha_s^2/(t - \mu_D^2)^2$ [5], with strong coupling constant $\alpha_s = 0.33$ and Debye screening mass $\mu_D = 2.265/\text{fm}$ (the total cross section is then $\sigma = 3 \text{ mb}$) for all AMPT simulation in our work. After partons stop interaction, a simple quark coalescence model is applied to combine two nearest partons

into a meson and three nearest partons into a baryon(or antibaryon). The hadronic interactions are described by the ART model [14]. We terminate the hadronic interactions at a cutoff time.

We simulate three collision systems: Au+Au collisions with $b = 6.6\text{--}8.1$ fm at the nucleon-nucleon center-of-mass energy $\sqrt{s_{\text{NN}}} = 200$ GeV, $d\text{+Au}$ collisions with $b = 0$ fm at $\sqrt{s_{\text{NN}}} = 200$ GeV, and $p\text{+Pb}$ collisions with $b = 0$ fm at $\sqrt{s_{\text{NN}}} = 5$ TeV by AMPT. We analyze the momentum-space azimuthal anisotropy of partons in the final state before hadronization, of hadrons right after hadronization before hadronic rescatterings take place, and of freeze-out hadrons in the final state. The momentum anisotropy is characterized by Fourier coefficients [15]

$$v_2 = \langle \cos 2(\phi - \psi_2^{(r)}) \rangle, \quad (1)$$

where ϕ is the azimuthal angle of the particle (parton or hadron) momentum. The $\psi_2^{(r)}$ is the harmonic plane of each event from its initial configuration of all partons. All results shown are for particles within pseudo-rapidity window $|\eta| < 1$.

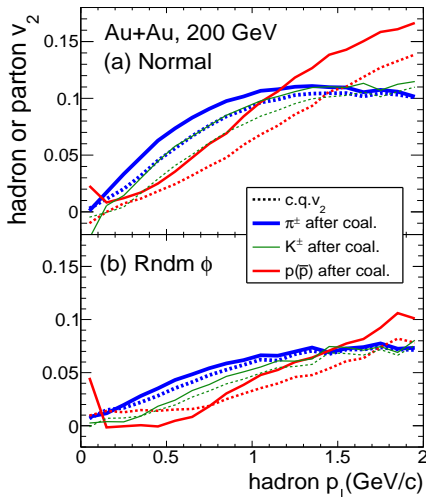


Figure 1. Mass splitting from coalescence. Constituent quark (c.q., dashed curves) and primordial hadron (solid curves) v_2 both as a function of hadron p_\perp in Au+Au collisions by normal (a) and ϕ -randomized AMPT (b).

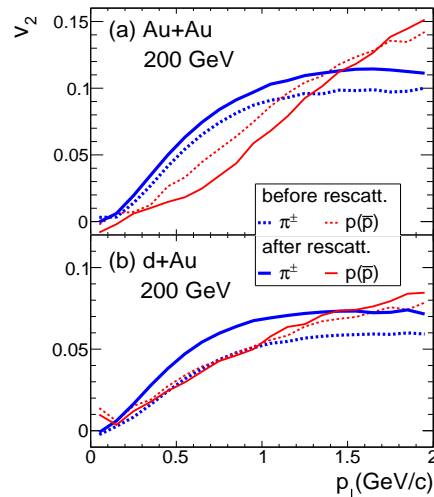


Figure 2. Effects of hadronic rescattering. Pion and (anti) proton v_2 before (dashed) and after (solid) hadronic rescatterings in Au+Au (a) and $d\text{+Au}$ (b) collisions by AMPT.

3. Mass ordering of v_2

Considering that observed pions and protons are made of only light constituent quarks, the difference between their v_2 should come from the hadronization process and/or hadronic rescattering. We first study the primordial hadrons right after hadronization, before any decay and hadronic rescatterings take place. Figure 1(a) shows the v_2 of primordial charged pion, kaon, and (anti)proton as a function of p_\perp (solid curves). It demonstrates that the mass ordering of v_2 at low p_\perp in AMPT comes from the dynamic in coalescence. The dynamical “selections” of constituent quarks into pions, kaons, and protons are manifest in the constituent quark v_2 distributions shown by the dashed curves in Fig. 1(a), plotted at the respective *hadron* p_\perp .

Figure 1(b) shows the v_2 results by ϕ -randomized AMPT [9] for primordial hadrons right after coalescence hadronization at the corresponding constituent quark v_2 ’s. No hydrodynamic

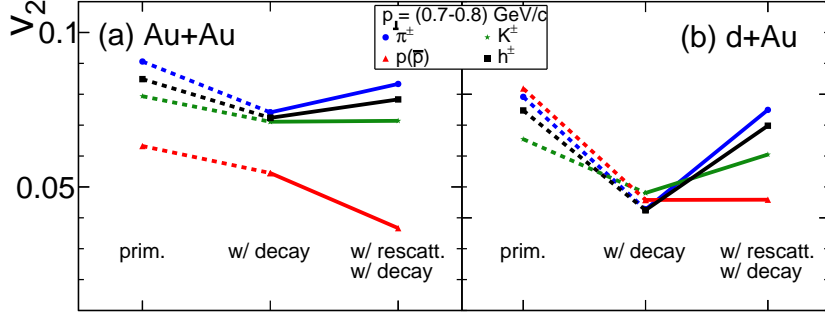


Figure 3. (Color online) Mid-rapidity ($|\eta| < 1$) v_2 of π , K , $p(\bar{p})$ and charged hadrons (h^\pm) at $0.7 < p_\perp < 0.8$ GeV/ c at different stages of system evolution in $b = 6.6-8.1$ fm Au+Au (left) and $b = 0$ fm d+Au (right) collisions at $\sqrt{s_{NN}} = 200$ GeV by AMPT: right after coalescence hadronization and before hadronic rescattering (initial v_2 of primordial hadrons), hadron initial v_2 including decays, and after hadronic rescattering at freezeout (hadron final v_2).

anisotropic flow is present in the ϕ -randomized case [9], however, mass splitting is still present. It implies that the mass splitting is mainly due to kinematics in the coalescence process. It is therefore not a unique signature of collective anisotropic flow or hydrodynamics.

After hadronization, particles undergo decay and rescattering. We evaluate the v_2 of hadrons before hadronic rescattering but including effects of resonance decays by setting the cut-off time to be 0.6 fm/ c . The results are shown in Fig. 2(a) by the dashed curves. The decay product v_2 is usually smaller than their parent v_2 [12]. By including decay products, the hadron v_2 is reduced from that of primordial hadrons (solid curves in Fig. 1(a)).

The v_2 values before hadronic rescattering (including resonance decay effects) can be considered as the initial v_2 for the hadronic evolution stage. The final-stage freezeout hadron v_2 's (also including decay daughters) are shown in Fig. 2(a) by the solid curves. Pion v_2 increases while proton v_2 decreases from before to after hadronic rescattering. This may be due to interactions between pions and protons, after which they tend to flow together at the same velocity. Thus, the same-velocity pions and protons (i.e. small p_\perp pions and large p_\perp protons) will tend to have the same anisotropy. It will yield lower v_2 for the protons and higher v_2 for the pions at the same p_\perp value. This should happen whether or not there is a net gain in the overall charged hadron v_2 , which depends on the initial configuration geometry from which the hadronic evolution begins [12]. The similar results in d+Au collisions as shown in Fig. 2(b) [12].

To summarize the origin of v_2 mass splitting, we plot the v_2 of pions, kaons, and protons within $0.7 < p_\perp < 0.8$ GeV/ c , a typical region for different stages of the collision system evolution as shown in Fig. 3. The evolution stages contain: (i) right after coalescence hadronization including only primordial hadrons (labeled “prim.”); (ii) right after coalescence hadronization but including decay products (labeled “w/ decay”); and (iii) at final freezeout (labeled “w/ rescatt. w/ decay”). We can see the mass ordering actually comes from interplay of several physics effects; it comes from coalescence, and more importantly, from hadronic rescattering process.

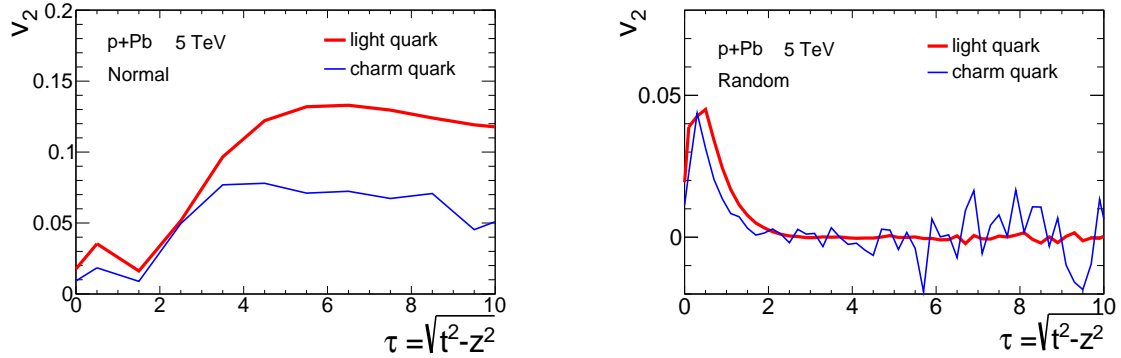


Figure 4. (Color online) The charm and light quark v_2 as a function of the proper time $\tau = \sqrt{t^2 - z^2}$ in p+Pb collisions with $b = 0$ fm. Both the normal (left) and ϕ -randomized AMPT (right) results are shown.

4. Charm v_2 mechanism

In this section we discuss the production mechanism of charm quark flow in pPb. We compare the light and charm quark freeze out v_2 , integrated over all p_\perp at the same proper time. This is shown in the left panel of Fig. 4. The charm v_2 is systematically lower than light quark v_2 . This may suggest that the charm quark is not as thermalized as light quarks. The right panel of Fig. 4 shows ϕ -randomized results. The charm and light quark v_2 are similar suggesting a common escape mechanism.

5. Summary

In these proceedings, we investigate the origin of mass splitting of identified hadron v_2 . The mass splitting is due to coalescence and, more importantly, hadronic rescattering. It is therefore not a unique signature of hydrodynamics. We also study the development of charm v_2 and found the escape mechanism to be the major contribution in pPb similar to light quarks.

Acknowledgments

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